LONDON STRATEGIC SUDS PILOT STUDY

Hydraulic Modelling, Technical Note

DECEMBER 2020

1 SUMMARY

This technical note covers the build and validation of InfoWorks ICM models required to enable hydraulic evaluation of flood damages and benefit. The models developed here are solely for use within this project and are not considered suitable for any other use.

A summary of the existing and developed model for each study catchment area is as follows:

- Enfield Town Centre CDA – Existing InfoWorks ICM 1D-2D Integrated model, no changes made
- Moore Brook Culvert CDA – Existing InfoWorks ICM 1D-2D Integrated model, no changes made
- Acre Road CDA – New 1D-2D InfoWorks ICM model, incorporating an existing InfoWorks ICM 1D model from Thames Water (TW)
- **Eastcote Town Centre CDA** - New 1D-2D InfoWorks ICM model
- **Westminster, Camden & Southwark** – x2 Existing InfoWorks ICM 1D models from Thames Water (TW) / new InfoWorks 2D model

2 EXISTING MODELS

2.1 Enfield Town Centre & Moore Brook Culvert CDAs, Enfield

For the Tier 3 Surface Water Flood Risk Modelling and Mitigation Studies previously completed, fully integrated 1D-2D hydraulic models were developed in InfoWorks ICM, including the TW public sewer network *(and ancillaries)*, LLFA owned / maintained sewers, culverted watercourses, road gullies *(LLFA and TfL)* and the New River Loop watercourse.

The development incorporated OS MasterMap to accurately define surface catchment features such as road kerbs *(-100mm)*, buildings thresholds *(+150mm)* and variable runoff surfaces. The 2D surface model combined 1m LIDAR survey information with surface features details. Runoff and infiltration characteristics for all surfaces were defined to enable rainfall infiltration to be calculated. The model utilised direct rainfall runoff. It was assumed that all property roofs drained directly to the surface water network via downpipes, modelled using 1D subcatchments connecting to the closest modelled manhole.

For the Enfield Town Centre CDA Several specific schemes were also included, shown below:

- **The New River Loop** - The New River Loop is a former section of the New River that was cut off from the main flow and maintained as a local amenity by Enfield Council. The New River Loop was included into the model as a river reach, linked to the 2D domain along its banks

- **Existing Flood Alleviation Schemes (FAS)** - The existing FAS schemes represented in the model were the Lancaster Road FAS *(Box culvert that provides additional storage capacity within the underground surface water system)*, Town Park Storage Tank FAS *(concrete storage tank located beneath Town Park and connected in parallel with the trunk surface water sewer through the park)* and Chase Side Crescent FAS *(precast concrete culvert tank located beneath the car park at the junction of Chase Side Crescent and Gordon Road)*

- **Civic Centre Underground Car Park** – Represented in the hydraulic model as a flood storage tank, beneath the civic centre, and linked to the 2D surface model with a dummy weir *(set at the LIDAR level of the road and the width of the entrance)*

For the Moore Brook Culvert CDA, the Firs Farm FAS scheme was included, a recently constructed community wetlands which provides surface water attenuation.

These models were later used to support the application for DEFRA funding via a Project Appraisal Report. No changes were made to the baseline model for this project

2.2 Eastcote Town Centre, Hillingdon

As part of the Eastcote Town Centre Flood Investigations[1] a Micro Drainage model was built to evaluate the existing drainage system and assist the evaluation of flood benefit. This model has not been used directly and / or imported into ICM.

The Micro Drainage model does not extend upstream to the effective catchment watershed, being constrained to the local drainage network serving Eastcote town centre and immediate side roads. It was established that runoff from areas higher up in the catchment which are served by discrete networks *(that drain via different routes)* would flow overland and could potentially influence floodwaters along Field End Road, once the capacity of the drainage system had been exceeded.

Another Micro Drainage model was also provided covering the track drainage along the Metropolitan line, bounding the CDA to the south. It was determined based on a review of the Eastcote Town Centre Flood Investigations report and the Thames Water (TW) network data that this network does not directly impact flood risk within this CDA. This model has not been used directly and / or imported into ICM.

2.3 Acre Road, Kingston

2.3.1 TUFLOW Model

As part of the Acre Road Surface Water Flood Investigation[2] project a linked 1D-2D TUFLOW model was built, using ESTRY to represent the drainage network. The model predictions were used support the evaluation of economic damages and flood mitigation options. The model includes the major surface water network and highway gullies, limited to the general extent of the CDA. It was anticipated that this model would be used for this study.

The TUFLOW model provides adequate resolution and detail for the 2D surface, sufficient to enable the granular predictions of gully flows and the hydraulic benefit of constructing SuDS. It also includes highway gullies at the boundary between the surface and the sewers. However, the coverage and detail of the surface water network is limited within the CDA and further upstream within the same drainage catchment. The model also does not include any of the foul / combined drainage network and its associated ancillaries.

2.3.2 Thames Water InfoWorks ICM Model

Following consultations with key stakeholders, a concern was raised by the London Borough of Kingston *(who commissioned the Acre Road Surface Water Model)* that, since the TUFLOW model did not include any of the foul / combined sewer network, the proposals from this study would not account for the wider risk from foul sources or benefit from SuDS. Following consultation, TW provided their InfoWorks ICM model covering the Kingston CDA *(SMG1632 Penrhyn Road, Kingston DIA)*. A critical review of both models was undertaken, the key findings being listed below:

- The TW model includes a full representation of the foul / combined and surface water networks, both of which have been subject to recent verification activities *(based on model flags)*
- The detail in the surface water network *(extent of network, small pipes, ancillaries etc.)* is significantly greater than the in the TUFLOW model
- The foul / combined and surface water networks appear to include all known piped cross-connections (*i.e. CSOs / EOs)*, plus pumping stations and storage ancillaries
- The general detail and content of the TW model would enable the efficient derivation of SuDS Scenarios *(based on the gully information and verified runoff areas)*

It was concluded that the most practical approach was to use the TW model to ensure consistency in modelling software and technical application of the SuDS Scenario methodology. Several adaptations to the TW model were necessary, which are outlined in Section 0.

[1] *Eastcote Town Centre Flood Investigations (04/10/2018), 1000004158/5*

[2] *Acre Road Surface Water Flood Investigation - Economic Appraisal Report (2016), CS\076488\5*

No details of the model development or verification have been provided.

2.4 Westminster & Camden

The Beckton STW catchment InfoWorks ICM 1D model was provided by TW which provided full coverage of the Westminster and Camden catchment extent, including all main foul, combined and surface water sewers. The model has been subject to a continuous development and re-verification process of many years, ensuring a sufficient level of confidence in its validity, accuracy and value of application to the project.

2.5 Southwark

The Crossness STW catchment InfoWorks ICM 1D model was provided by TW which provided full coverage of the Southwark catchment extent, including all main foul and combined sewers, plus selected and surface water trunk sewers. The model is considered a WaPUG Type I skeletal model was has not been subject to a recent verification. The lack of network detail is considered to impact the confidence of the project, but infilling network detail was not considered necessary due to the model approach applied (See Section 5.2).

3 EASTCOTE TOWN CENTRE, HILLINGDON

3.1 DATA & INFORMATION

The primary data sources used to support the model build and validation are listed in Table 1.

Data	Source	Purpose	Quality
Sewer Network Data	TW	To represent the public drainage network across the CDA *(excluding highway drainage and laterals)*	Generally good, with some minor data omissions and irregularities
OS MasterMap	EA	Develop all the essential 2D elements and topographic features	Excellent
Gully locations	London Borough of Hillingdon	To include the highway drainage system	Reasonable
1m LiDAR	EA	Generate elevation data for the 2D surface, infer manhole cover levels (where data is missing) and interpolate gully grate levels	Excellent

Table 1 – Eastcote Town Centre, Data & Information

3.2 TECHNICAL APPROACH

A new integrated 1D-2D InfoWorks ICM model has been built.

The modelling approach is highly comparable to that of the other CDAs being evaluated as part of the overall London Pilot SuDS Project. This ensures the methodology for undertaking scenario testing of SuDS features can be efficiently and accurately applied to this CDA, maintaining consistency and comparability of model results for cross-CDA analysis.

It has been assumed that the catchment is separately sewered, based presence of both a foul and surface water network. It has also been assumed that all roof runoff is directly connected to the public drainage system, via guttering and downpipes *(i.e. does not run onto paved surfaces or into soakaways)*.

3.3 MODEL BUILD

3.3.1 1D Network

The TW network data was imported directly into the model. Missing or erroneous data was amended and / or interpolated based on sensible modelling judgement, and with reference to the EA LiDAR data where necessary. At the downstream end of each discrete network a fixed top water level, equivalent to pipe soffit level, has been applied to represent potential downstream surcharge.

Sediment has been applied to the network based on pipe capacity and typical self-cleansing velocity. Sediment has been applied to each pipe pro rata, based on the assumption that maximum sedimentation occurs at a gradient of effectively zero and there is no sedimentation at the gradient calculated to provide self-cleansing velocity.

3.3.2 2D Elements

The 2D elements created to facilitate the development of a detailed 2D surface are as follows:

- **Mesh Zones** – Used to define road curb edges and building threshold levels, plus the definition of variable resolution *(based on land use classification)*
- **Roughness Zones** – Used to define variable roughness parameters based on land use classification data
- **Infiltration Zones** - Use to define dynamic 2D infiltration

All these elements were developed from the raw OS MasterMap Topographic data.

The values for topographic adjustment and the definition of resolution within the Mesh Zones are listed in Appendix A. The roughness parameters applied to the Roughness Zones are listed in Appendix B.

3.3.3 1D-2D Interface

The model includes all known public highway gullies with their lateral connections to the public sewer interpolated based on proximity only.

The highway gully network has been represented using specific inlet records in InfoWorks ICM. Typical gully dimensions have been assumed, including gully pot depth and lateral pipe diameter. It was been assumed that all gullies are 10% blocked.

3.3.4 1D Subcatchments

Subcatchments have been generated using the OS MasterMap land use classification ‘Buildings’, representing roof runoff. Their discharge location has been interpolated based on proximity only.

3.4 VALIDATION

3.4.1 EA Flood Mapping

The modelled flood extents for the 1 in 30-year and 1 in 100-year events have been used to benchmark flood extent and depth predictions against the EA Surface Water Flood Maps. A critical event duration of 90 minutes as been used, evaluated as demonstrating the greatest extent of flooding across events ranging from 30 minutes to 3 hours.

The model predictions match the EA flood mapping relatively well along Field End Road, although a greater extent and depth is predicted for the 1 in 30-year event. There are other minor discrepancies across the CDA, but the overall correlation and primary overland flow routes are well replicated.

3.4.2 Flood History

Significant flooding on Field End Road occurred on the 23rd June 2016, recorded in the Eastcote Town Centre Flood Investigations report and evaluated to equate to a 1 in 1-year 60-minute event. An equivalent design event was simulated and has been compared to the photographic evidence, as shown in Figure 1.

Flood Image	New Model

Figure 1 - Evidence of Flooding Correlated With Model Predictions

The correlation of flood extent is considered very good. The photograph indicates floodwaters do not exceed around 0.1m in depth, since the pavement on the eastern side of the road remains above the floodwaters and based on the observed depth of water against the cars captured driving through the flooding.

4 ACRE ROAD, KINGSTON

4.1 DATA & INFORMATION

The primary data sources used to support the model adaptation and validation are listed in the following table.

Data	Source	Purpose	Quality
Network Data	TW	To represent the public drainage network across the CDA *(excluding highway drainage and laterals)*	Generally good, with some minor data omissions and irregularities
OS MasterMap	London Borough of Kingston	Develop all the essential 2D elements and topographic features	Excellent
Gully locations	TUFLOW Model	To include the highway drainage system	Reasonable
1m LiDAR	EA	Generate elevation data for the 2D surface, infer manhole cover levels (where data is missing) and interpolate gully grate levels	Excellent

Table 2 – Acre Road, Data & Information

4.2 TECHNICAL APPROACH

The TW InfoWorks ICM model has been converted from a 1D network model into an integrated 1D-2D model. Paved and permeable runoff, previously specified within the model subcatchments based on defined areas, is generated from 2D direct rainfall runoff. Roof areas have been retained within new subcatchments which only represent roofs discharging runoff directly to the sewers via their guttering and down pipes.

The main model development activities are as follows:

- Converting the existing TW model subcatchments into specific property subcatchments, with the percentage of total runoff adjusted to match the verified model *(to maintain confidence in its verified flows, especially within the foul system)*
- Inclusion of the gully information *(taken from the TUFLOW model)*, connected up based on the verified destination of flow in from the existing TW model
- Cropping of parts of the ICM baseline model which do not interact with the 2D area covering the CDA, as defined in the TUFLOW model
- Creation of the 2D model *(based on standard approach and adjusted to match the general resolution parameters using in the TUFLOW model)*

4.3 MODEL BUILD

4.3.1 1D Network

No dimensional or connectivity changes have been made to the public sewer network

The model was cropped to match the project extent at the Sewage Treatment Works inlet pumping station and at network bifurcations *(where flows are routed to a discrete network)*.

4.3.2 2D Elements

The 2D elements created to facilitate the development of a detailed 2D surface are as follows:

- **Mesh Zones** – Used to define road curb edges and building threshold levels, plus the definition of variable resolution *(based on land use classification)*
- **Roughness Zones** – Used to define variable roughness parameters based on land use classification data
- **Infiltration Zones** - Use to define dynamic 2D infiltration

All these elements were developed from the raw OS MasterMap data. To maintain consistency key hydraulic parameters derived for the existing TUFLOW model have been applied to the new model. These include the infiltration parameters, 2D surface roughness values and the maximum spatial resolution of the 2D surface.

The values for topographic adjustment and the definition of resolution within the Mesh Zones are listed in Appendix A. The roughness parameters applied to the Roughness Zones are listed in Appendix B.

4.3.3 1D-2D Interface

The model includes all known public highway gullies. The definition of connectivity has been based on the existing TW model subcatchment boundaries, with lateral connections to the public sewer being interpolated accordingly.

The highway gully network has been represented using manhole records with typical gully dimensions applied, including gully pot depth and lateral pipe diameter. It was been assumed that all gullies are 10% blocked.

4.3.4 1D Subcatchments

Property subcatchments have been generated using the OS MasterMap land use classification of ‘Buildings’, representing roof runoff. Each subcatchment was duplicated, one representing foul / combined runoff and one surface water. With reference to the existing TW model subcatchments the proportional roof area compared to the actual available roof area *(calculated from OS MasterMap)* has been used as an adjustment factor for each property roof. This ensures that the net area in the new model closely matches the sum of subcatchment roof areas in the existing TW model.

Their discharge location has been interpolated directly from the existing TW model.

4.4 VALIDATION

The aim of the validation exercise is to ensure confidence in model predictions, specifically the general extent and depth of surface water flooding. Due to the inherent increase in complexity of runoff generation and routing, differences between this model and previous models are expected. The existing TW model, although a 'verified' model, is not capable of simulating overland flows and runoff originating from large permeable areas. As a result, it is expected that model correlation will diverge as return period increases, the system capacity becomes overwhelmed and the prevalence of overland flows increases.

4.4.1 Surface Water Flood Predictions

4.4.1.1 TUFLOW Model

The modelled flood extents for the 1 in 10, 25 and 50-year events have been used to benchmark flood extent and depth predictions against the TUFLOW model predictions, shown in Appendix C.

The general correlation of flood extent and depth is considered good, demonstrating that the 2D model development approach closely matches and replicates the TUFLOW model.

4.4.2 Pipe Flow Predictions

4.4.2.1 Network Surcharge & Flooding

The spatial variation of network surcharge and flooding between the existing TW model and new model for a 1 in 2, 5 and 10-year event is shown in Appendix C.

The general correlation during the 1 in 2-year events is relatively good, largely due to runoff being limited to paved urban areas. As the return period increases the new model predicts greater sewer depths across many areas of the catchment, driven by increased permeable runoff.

The significant difference in predicted sewer depths within the area, especially during the 1 in 10-year, is due to the existing TW model having very limited verified paved areas within both the foul and surface water systems. Runoff generated in this area in the new model is being routed to both systems overland, entering via known gully locations and elevating water levels. This discrepancy is considered to be highlighting a potential omission of runoff area within the existing model, rather than an over prediction of runoff and sewer flows.

4.4.2.2 Pipe Depth & Flow

The comparison of average peak flow depth and cumulative flow has been used to evaluate variation in pipe hydraulics and clarify confidence in the translation of existing subcatchment areas (See Section 4.3.4).

Model predictions for all pipes have been extracted and from both the existing TW model and new model for the 1 in 2, 5 and 10-year events. Larger return period events have not been used for this evaluation as predicted differences are expected to be more significant *(due to the enhanced complexity and integration of the 2D surface fundamentally changing the effective watersheds for the drainage system)* as rainfall intensity and runoff volume increases, rendering these comparisons inappropriate.

The modelled average differences are outlined in Table 3.

System	Maximum Flow Depth (m)			Cumulative Flow (%)		
	1 in 2-year	1 in 5-year	1 in 10-year	1 in 2-year	1 in 5-year	1 in 10-year
Foul / Combined	0.0	0.3	0.3	5%	9%	11%
Surface Water	0.0	0.2	0.3	14%	5%	12%
Whole System	0.0	0.2	0.3	5%	7%	12%

Table 3 – Acre Road Calibration, Modelling Differences

During the 1 in 2-year event the average change in depth is less than 0.1m, demonstrating good general correlation. The depth difference does increase during the 1 in 5 and 10-year events to between 0.2 and 0.3m. However, this is considered minor in the context of the scale of the network and change in model complexity.

The increase in cumulative flow is attributed to the increased runoff occurring from the 2D surface and full representation of the highway drainage system, allowing more surface water to enter the drainage system. The difference in foul flows is limited to 11% which is considered reasonable. The gradual divergence of flow depth and cumulative flow predictions as the return period increases demonstrates the effect greater volumes of surface runoff entering the drainage system, as large permeable areas become saturated and the effective runoff watersheds exceed the fixed areas applied to the existing TW model subcatchments.

5 WESTMINSTER, CAMDEN & SOUTHWARK

5.1 Data & information

The primary data sources used to support the model build and validation are listed in Table 4.

Data	Source	Purpose	Quality
Sewer Network Data	TW	To represent the public drainage network across the CDA *(excluding highway drainage and laterals)*	Generally good, with some minor data omissions and irregularities
OS MasterMap	EA	Develop all the essential 2D elements and topographic features	Excellent
Gully locations	London Borough of Westminster, Camden & Southwark	To include the highway drainage system	Reasonable
1m LiDAR	EA	Generate elevation data for the 2D surface, infer manhole cover levels (where data is missing) and interpolate gully grate levels	Excellent

Table 4 – Westminster, Camden & Southwark, Data & Information

5.2 Technical Approach

5.2.1 Preferred Approach

It was initially proposed that a full integrated 1D-2D model was developed, enhancing the TW model with a detailed 2D runoff model. Subject to initial testing and a preliminary development phase it was discovered that this was not technically practical within this project due to the large simulation run-times (2-5 days). The main impacts that these simulations times would have had are as follows:

- Limitation of the number of runs that could be simulated
- Limited the number of different SuDS Evaluation Scenarios that could be assessed
- Reduce the extent of the economic evaluation by limiting the statically robustness
- Creation of large results datasets for evaluation

An alternative approach was developed and applied.

5.2.2 Selected Approach

To address the issued discussed in Section 5.2.1 it was decided to develop a 2D only model to supplement the TW 1D models. The models were mutually calibrated / validated to ensure representative predictions whilst enabling relatively fast simulation times (compared to the testing for the Preferred approach).

The drainage system in the 2D model was accounted for using the 1D model predictions and gully location data provided, enabling the calibration of runoff discharge rates. The resulting model predictions are considered to be highly indicative of what a fully integrated 1D-2D model would generate.

An overview of the modelling calibration workflow is shown in Figure 2.

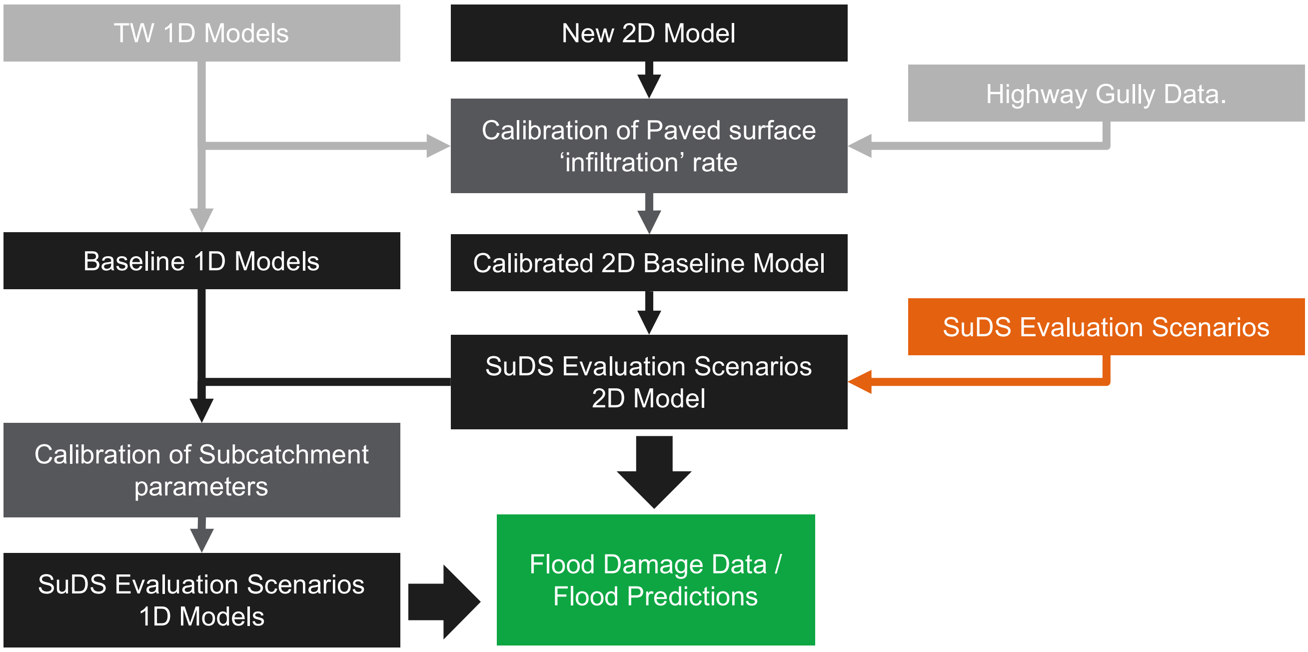

Figure 2 - Westminster, Camden & Southwark, Model Development Workflow

5.3 New 2D Model Development

5.3.1 Physical & Topographic Parameters

The 2D elements created to facilitate the development of a detailed 2D surface are as follows:

- **Mesh Zones** – Used to define road curb edges and building threshold levels, plus the definition of variable resolution *(based on land use classification)*
- **Roughness Zones** – Used to define variable roughness parameters based on land use classification data
- **Infiltration Zones** - Use to define dynamic 2D infiltration

All these elements were developed from the raw OS MasterMap data. The values for topographic adjustment and the definition of resolution within the Mesh Zones are listed in Appendix A. The roughness parameters applied to the Roughness Zones are listed in Appendix B.

5.3.2 Highway Drainage

Highway drainage was modelled based on predicted water levels from the 1D models, theoretical gully discharge rates and gully location data, which enabled the effective capacity of the sewerage network to be accounted for in the 2D model.

Infiltration Zones have been included for all road OS MasterMap polygons. A set of banded effective highway drainage rates (mm/hr) were calculated, representative of the effective total capacity of all highway gullies contained within each polygon. The theoretical gully discharge rate was specified based on research by the University of Sheffield[3], which provided empirical evidence of an average discharge rate of 0.01 m^3/s with a

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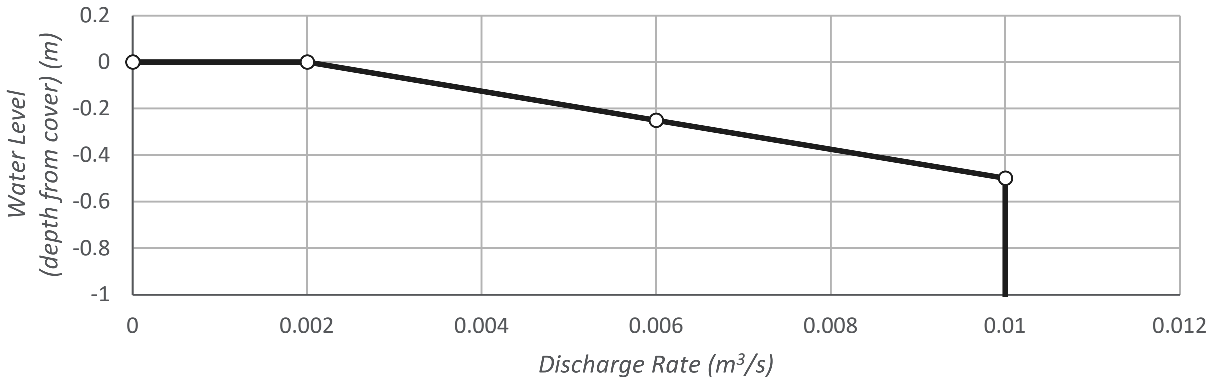
3 http://etheses.whiterose.ac.uk/11506/1/HYDRAULIC%20INTERACTION%20BETWEEN%20THE%20ABOVE%20AND%20BELOW%20GROUND%20DRAINAGE%20SYSTEMS%20VIA%20GULLY%20INLETS.pdf

free discharge into the gully (asm. at 0.5 m depth). This is based on typical UK gully grate dimensions. This assumption enabled the specification of a head-discharge relationship, which was used to extrapolate gully discharge rates based on modelled node water levels.



5.3.2.1 Calibration of Highway Drainage

The calculation of highway drainage rates parameters (applied to the Infiltration Zones) for the 2D model is described below:

1. Count of number of gullies contained within each OS MasterMap polygon
2. Identification of peak 1 in 30-year flood depth for model nodes located within each OS MasterMap polygon
3. Calculation of net discharge rate (m^3/s) for each OS MasterMap polygon (i.e. no of gullies x theoretical gully discharge rate)
4. Calculation of effective highway drainage rates for each OS MasterMap polygon (i.e. net discharge rate / area)
5. Derivation of set banded highway drainage rates, based on percentiles of all calculated values

The use of banded rates was considered necessary to avoid the need to derive thousands of individual infiltration surface profiles. The defined banded rate profiles used in the model are shown in Appendix E.

An example of the infiltration rate parameters applied to the model can be seen below:

5.4 SuDS Evaluation 1D Model Calibration

Representing the SuDS Evaluation Scenarios in the 1D models required the proportional reduction of subcatchment runoff areas, accounting for the effective volume of SuDS features proposed within each subcatchment.

It was assumed that SuDS features would be designed with a 1 in 30-year level of service (on average). Subcatchment runoff area reductions were calculated based on the effective volume and 1 in 30-year event total flood depth.

6 FITNESS FOR PURPOSE

This models presented here have been developed solely to facilitate the evaluation of Distributed SuDS for the London SuDS Pilot Study, based on the overarching project methodology. The model predictions are considered suitable for the high-level evaluation of strategic economic and flood risk mitigation value. The model predictions are not considered suitable for the evaluation of specific SuDS (or other drainage) schemes at a less then strategic level, without further validation of predictions, parameters and assumptions against relevant data and information, such as surveys.

APPENDIX A

Mesh Zone Parameters

Surface Type	Maximum Triangle Area (m^2)	Override 2D zone Minimum Element Area	Minimum Element Area (m^2)	Ground Level Modification	Raise by (m)
Public Road	10	TRUE	5	Raise or Lower	-0.1
Building	Total polygon area	TRUE	Total polygon area	Raise or Lower	0.1
Non-public Road / Track	10	TRUE	2	Raise or Lower	-0.05
Water	Total polygon area	TRUE	Total polygon area	None	-0.1
Cliff or Slope	2	TRUE	1	None	
Forest	25	TRUE	10	None	
Gardens	25	TRUE	5	None	
Rail	50	TRUE	25	None	
Traffic Calming	Total polygon area	TRUE	Total polygon area	Raise or Lower	0.1
Pavements	5	TRUE	2	Raise or Lower	0.05
General				None	
Paved Surfaces	25	TRUE	5	None	
Marsh				Raise or Lower	-0.1

APPENDIX B

Roughness Zone Parameters

Surface Type	Value	Source
Buildings	1	Chow (1959)
Concrete	0.017	Chow (1959)
Garden	0.1	Chow (1959)
Roads & Paths	0.04	Chow (1959)
Rail	0.017	Chow (1959)
short grass	0.03	Chow (1959)
high grass	0.035	Chow (1959)
no crop	0.03	Chow (1959)
mature row crops	0.035	Chow (1959)
mature field crops	0.04	Chow (1959)
scattered brush, heavy weeds	0.05	Chow (1959)
light brush and trees, in winter	0.05	Chow (1959)
light brush and trees, in summer	0.06	Chow (1959)
medium to dense brush, in winter	0.07	Chow (1959)
medium to dense brush, in summer	0.1	Chow (1959)
dense willows, summer, straight	0.15	Chow (1959)
cleared land with tree stumps, no sprouts	0.04	Chow (1959)
same as above, but with heavy growth of sprouts	0.06	Chow (1959)
heavy stand of timber, a few down trees, little	0.1	Chow (1959)
undergrowth, flood stage below branches		Chow (1959)
same as above with flood stage reaching branches	0.12	Chow (1959)
Water	0.0001	-

APPENDIX C

Validation Plans

Flood Depth & Extent - 1 in 30 Years

EA Surface Water Flood Maps	New InfoWorks ICM Model	Key
		

Flood Depth & Extent - 1 in 100 Years

EA Surface Water Flood Maps

New InfoWorks ICM Model

Key

Flood Depth (m)

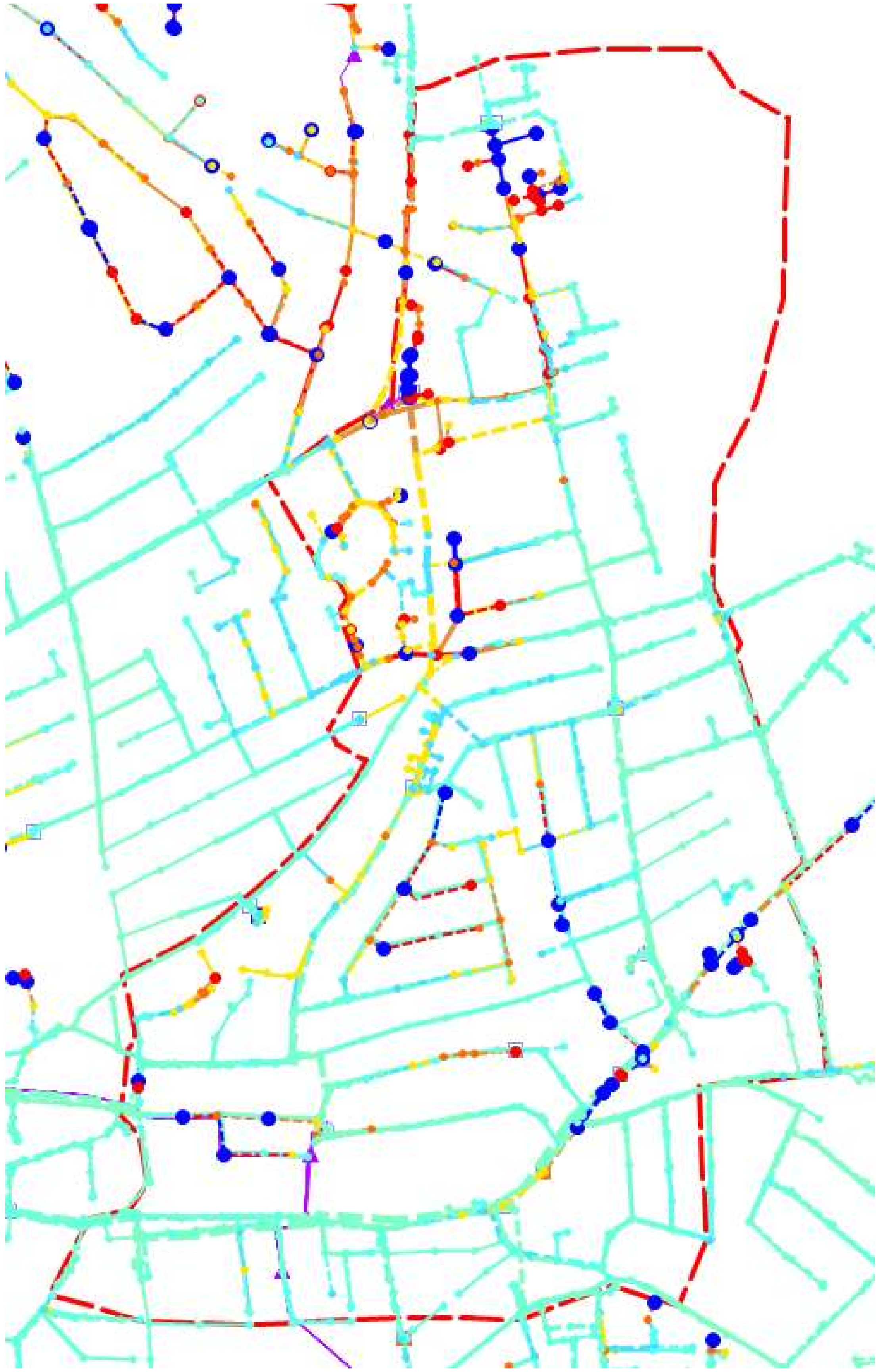
- Over 900mm
- 300 to 900mm
- Below 300mm

APPENDIX D

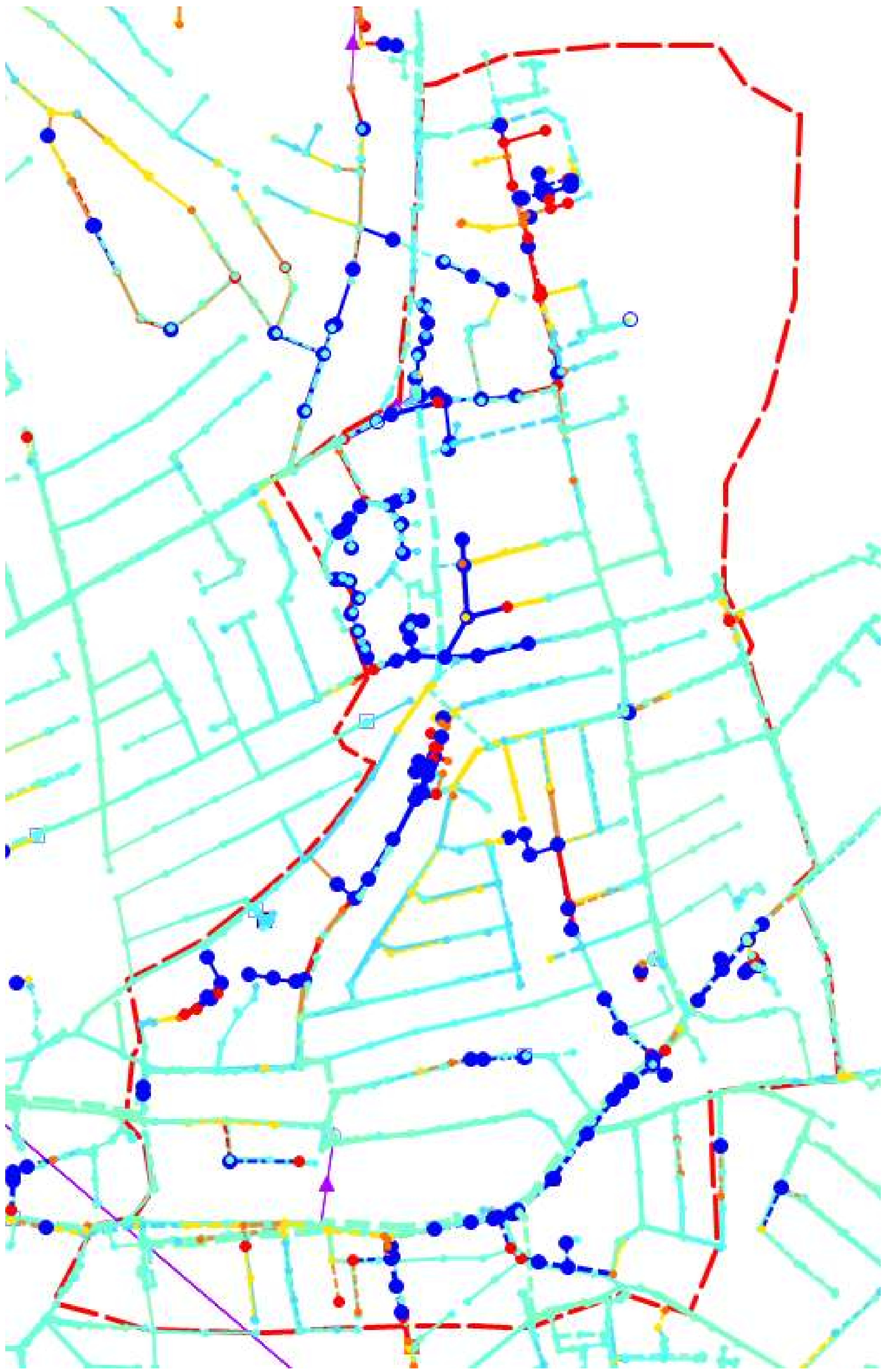
Model Predictions Validation Plans

Network Flow Depths – 1 in 2 Years

Existing InfoWorks ICM Model



New InfoWorks ICM Model



Key

Sewer Headroom (m)

- < -2
- >= -2
- >= -1
- >= -0.75
- >= -0.5
- >= -0.25
- >= -0.1
- >= 0

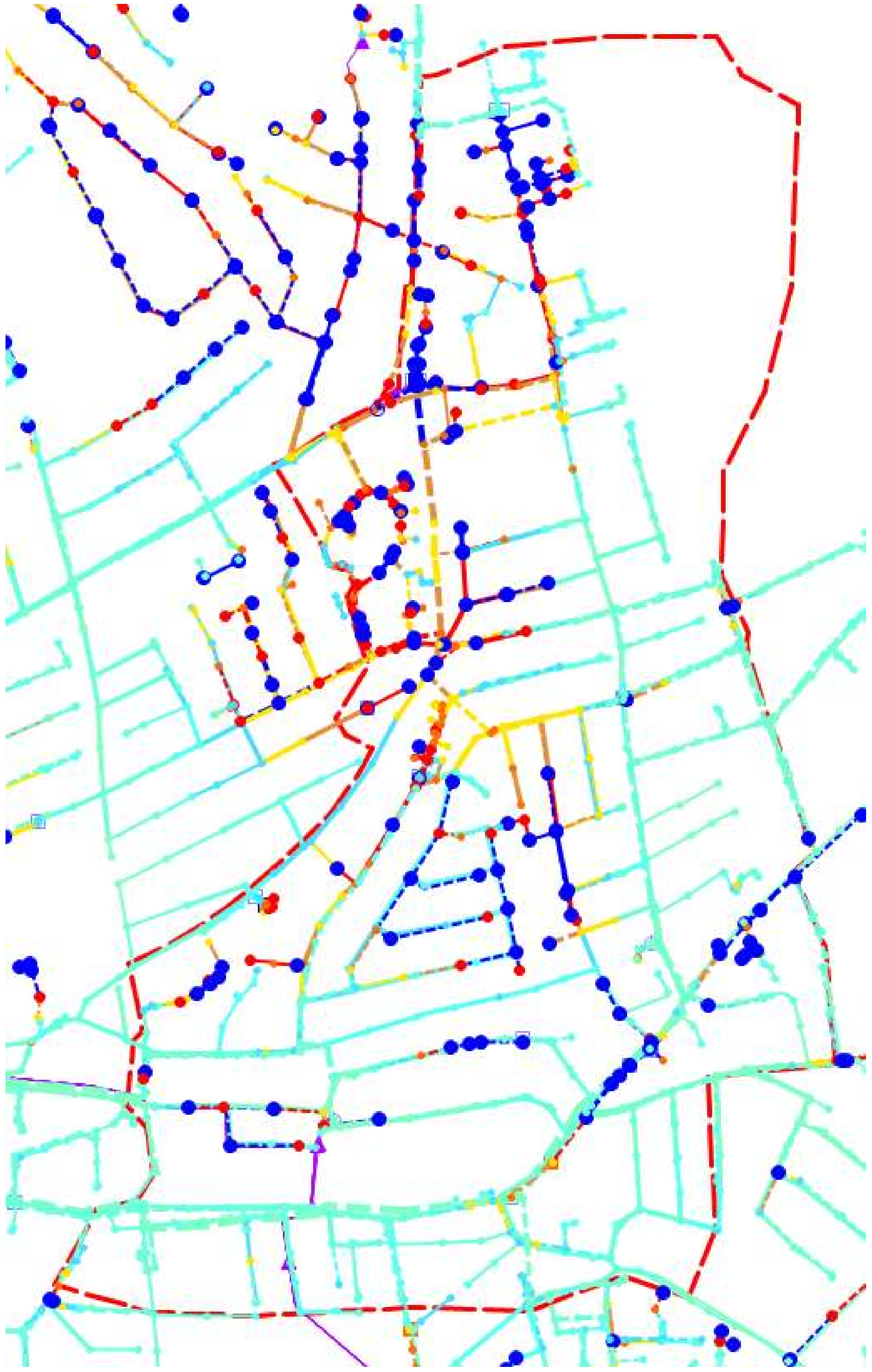
Manhole Headroom / Flooding (m)

- < -2
- >= -2
- >= -1
- >= -0.75
- >= -0.5
- >= -0.25
- >= -0.1
- >= 0

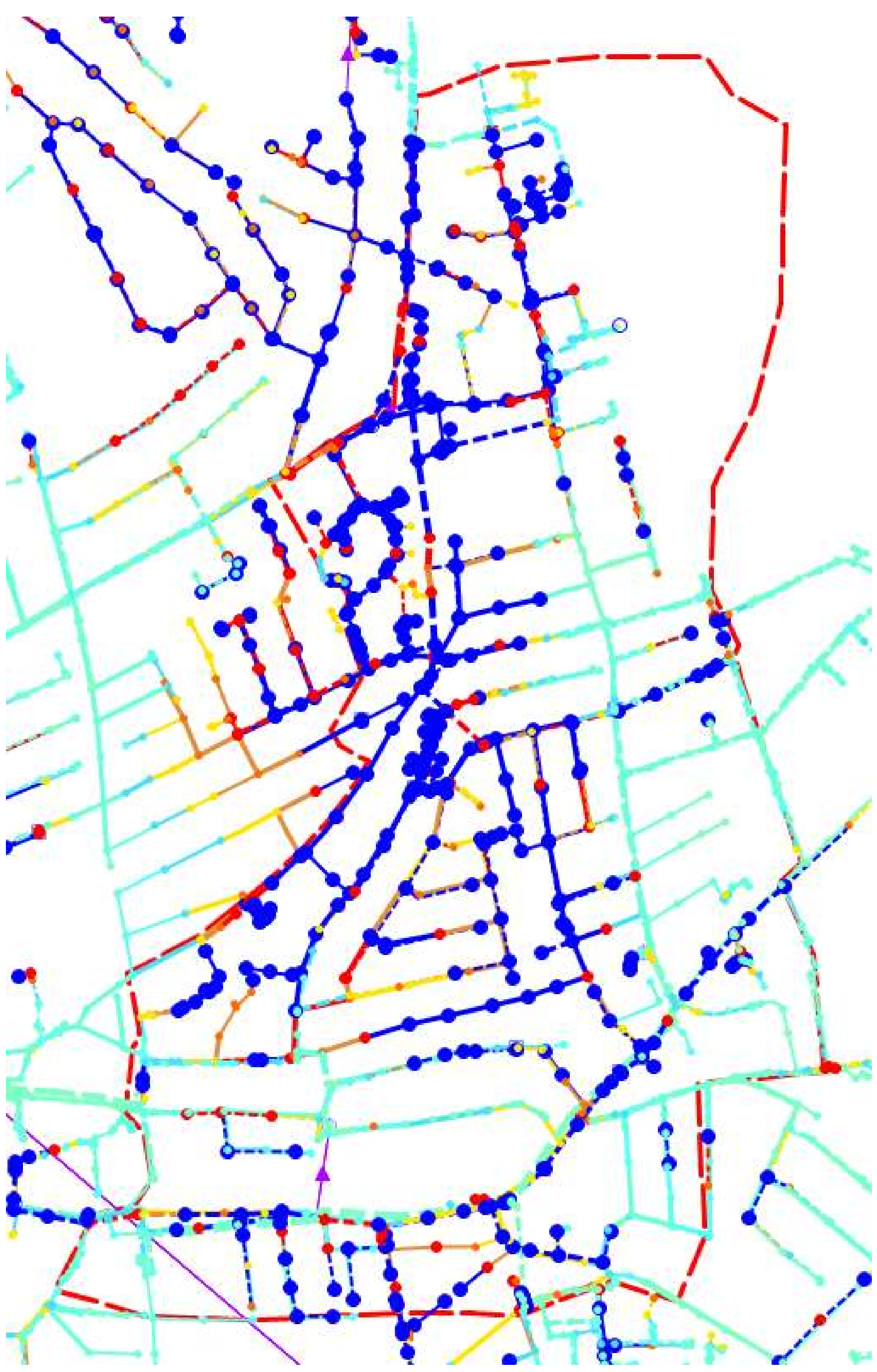
Network Flow Depths – 1 in 5 Years

Existing InfoWorks ICM Model	New InfoWorks ICM Model	Key

Existing InfoWorks ICM Model



New InfoWorks ICM Model



Key

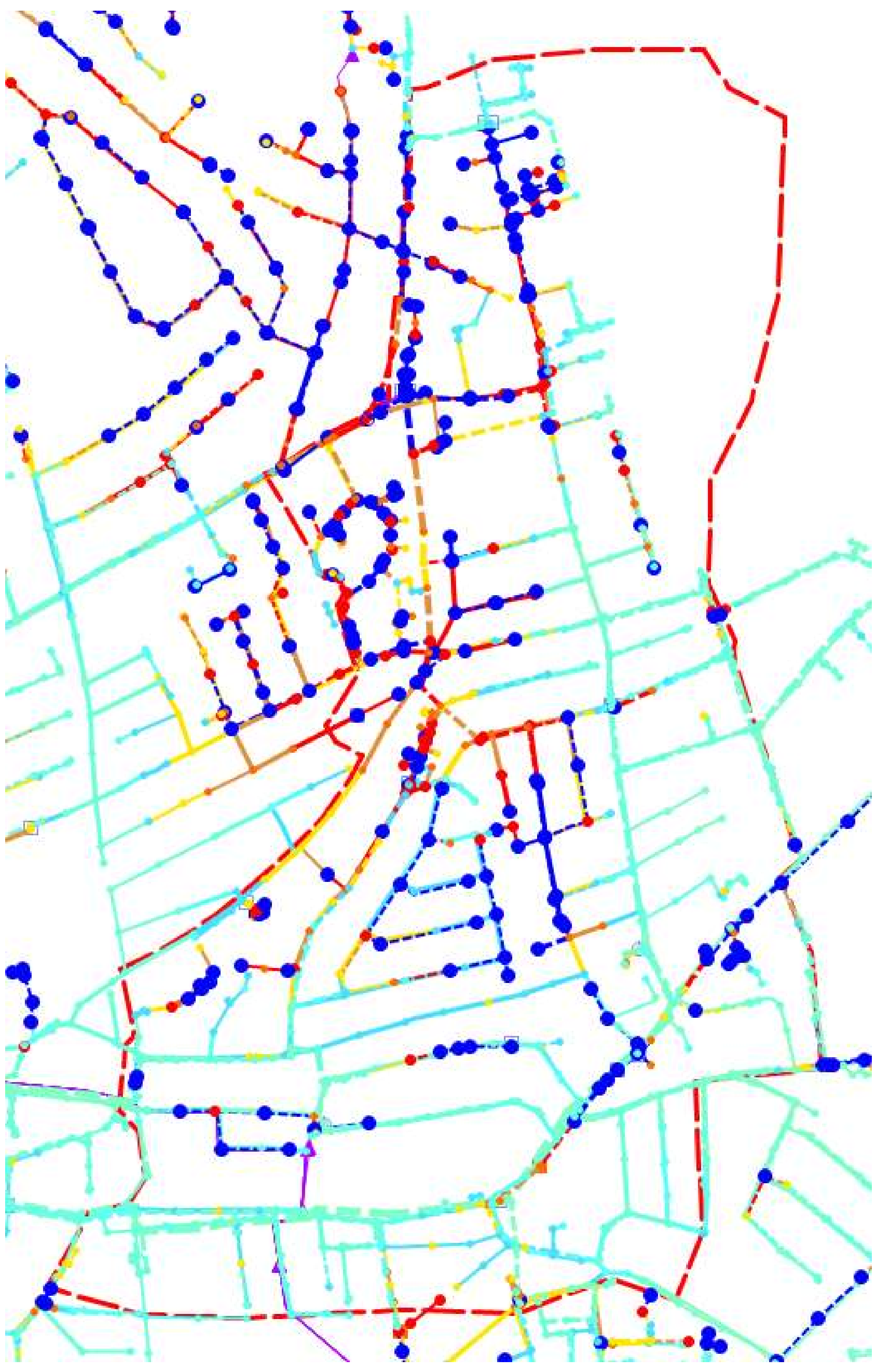
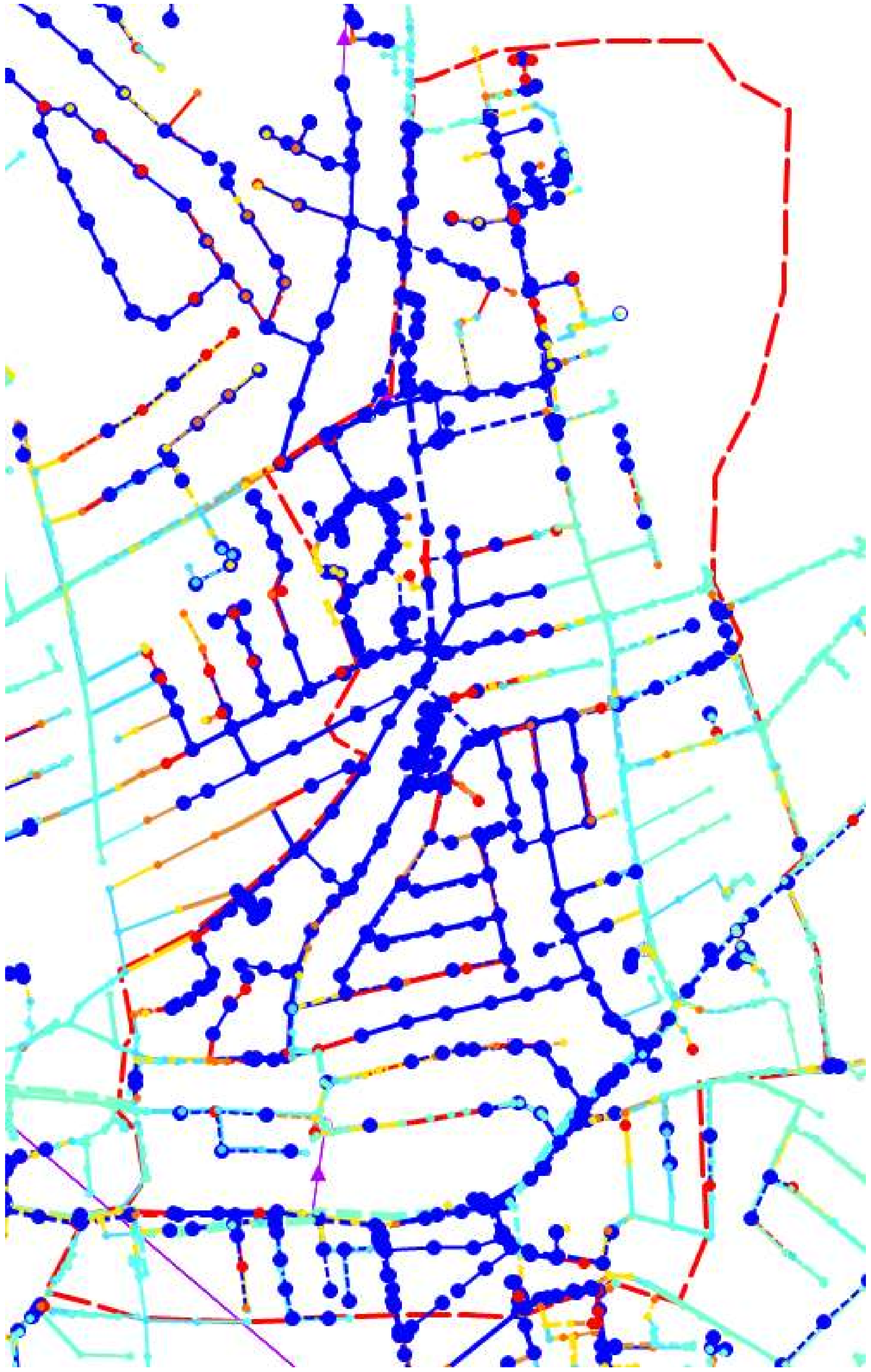
Sewer Headroom (m)

- < -2
- >= -2
- >= -1
- >= -0.75
- >= -0.5
- >= -0.25
- >= -0.1
- >= 0

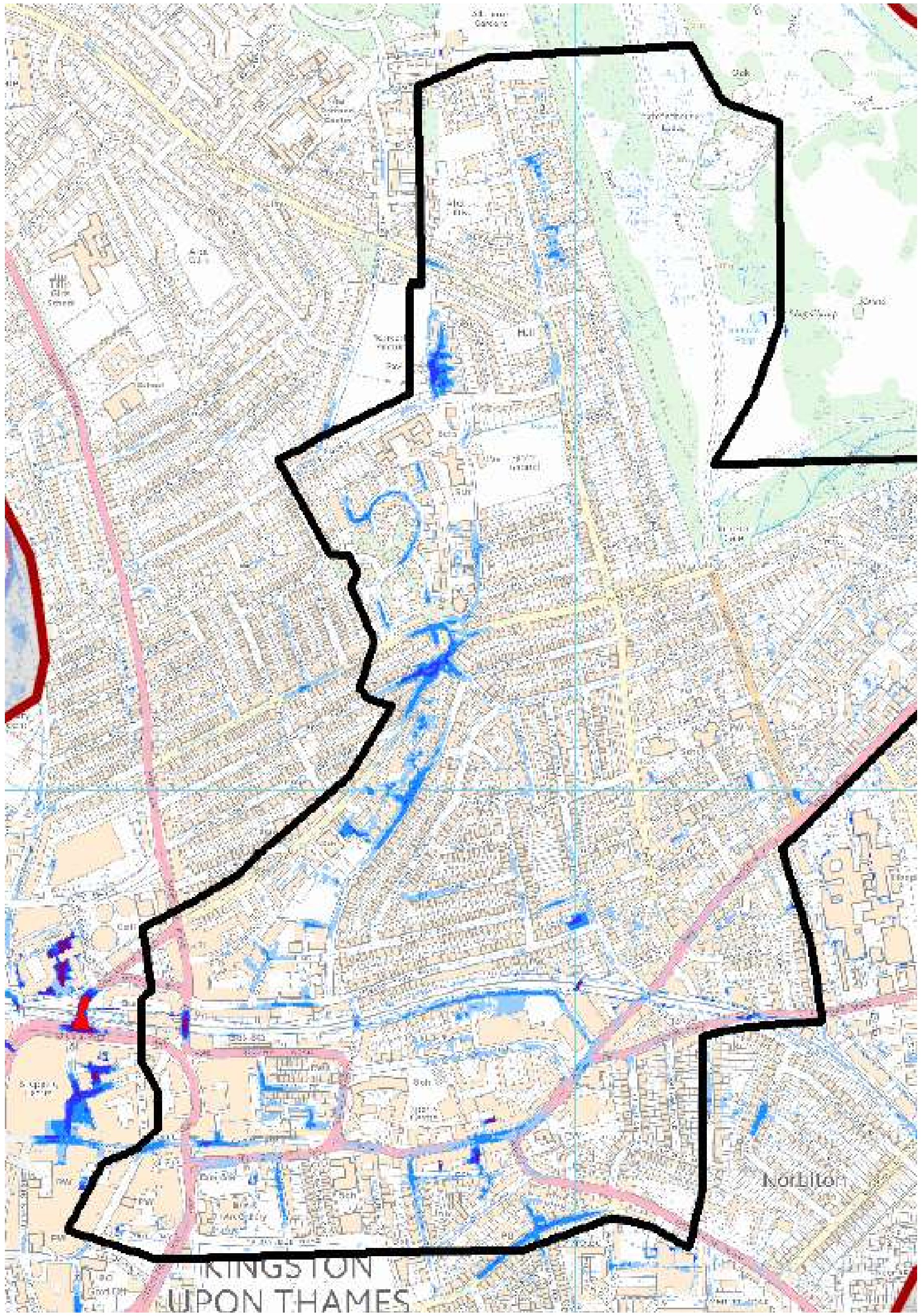
Manhole Headroom / Flooding (m)

- < -2
- >= -2
- >= -1
- >= -0.75
- >= -0.5
- >= -0.25
- >= -0.1
- >= 0

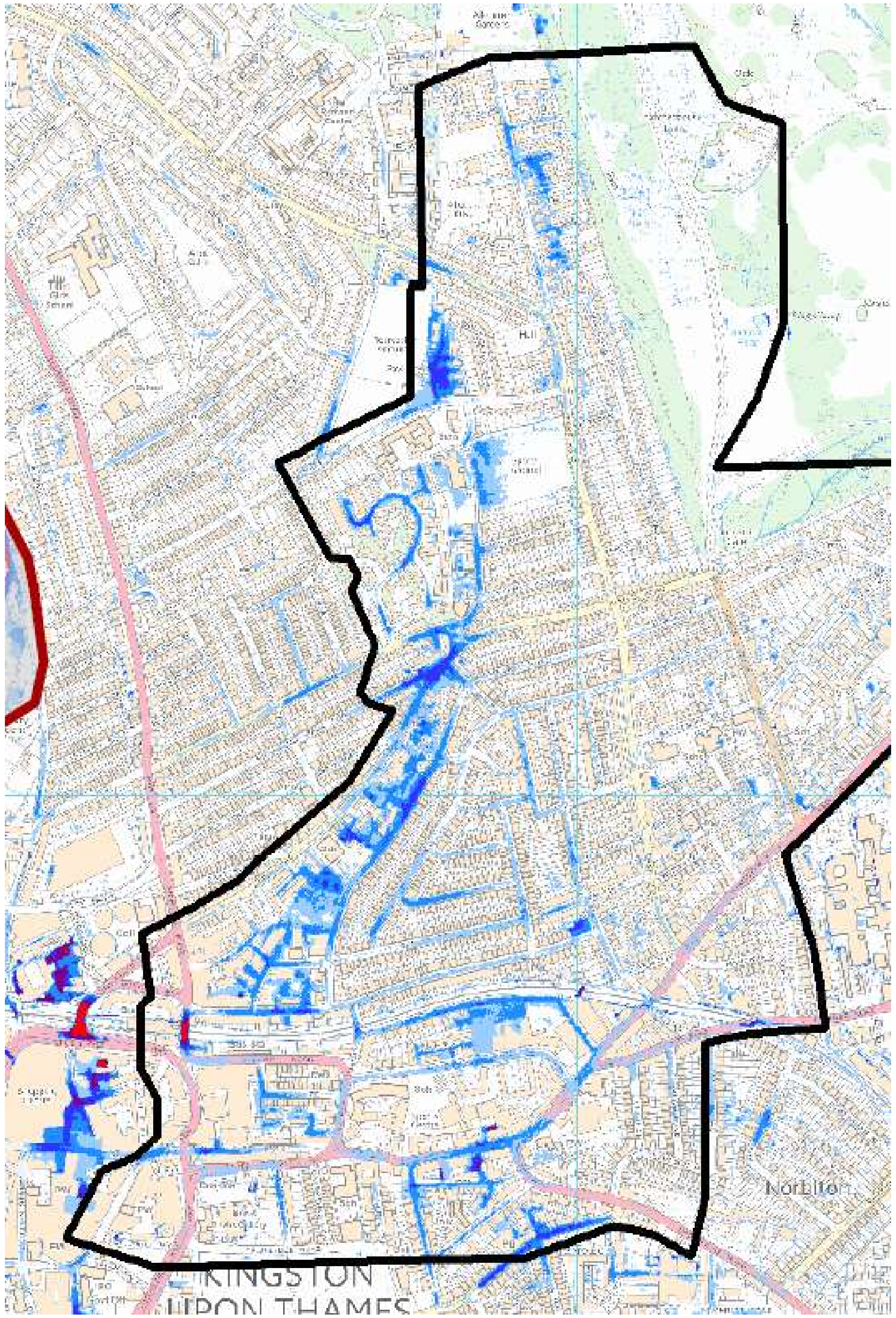
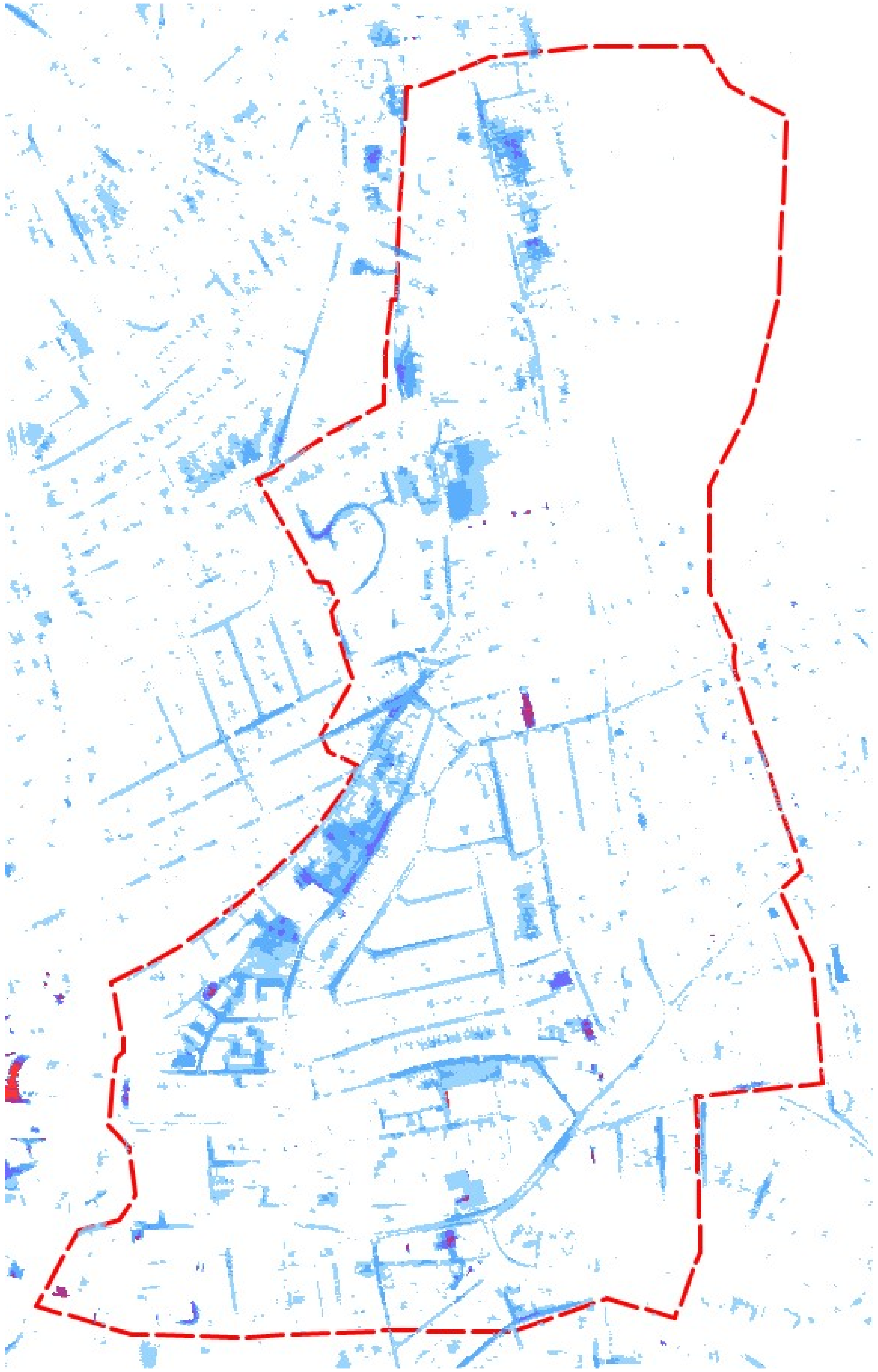
Network Flow Depths – 1 in 10 Years

Existing InfoWorks ICM Model	New InfoWorks ICM Model	Key
		Sewer Headroom (m) < -2 >= -2 >= -1 >= -0.75 >= -0.5 >= -0.25 >= -0.1 >= 0 Manhole Headroom / Flooding (m) < -2 >= -2 >= -1 >= -0.75 >= -0.5 >= -0.25 >= -0.1 >= 0

Surface Water Flooding – 1 in 10 Years

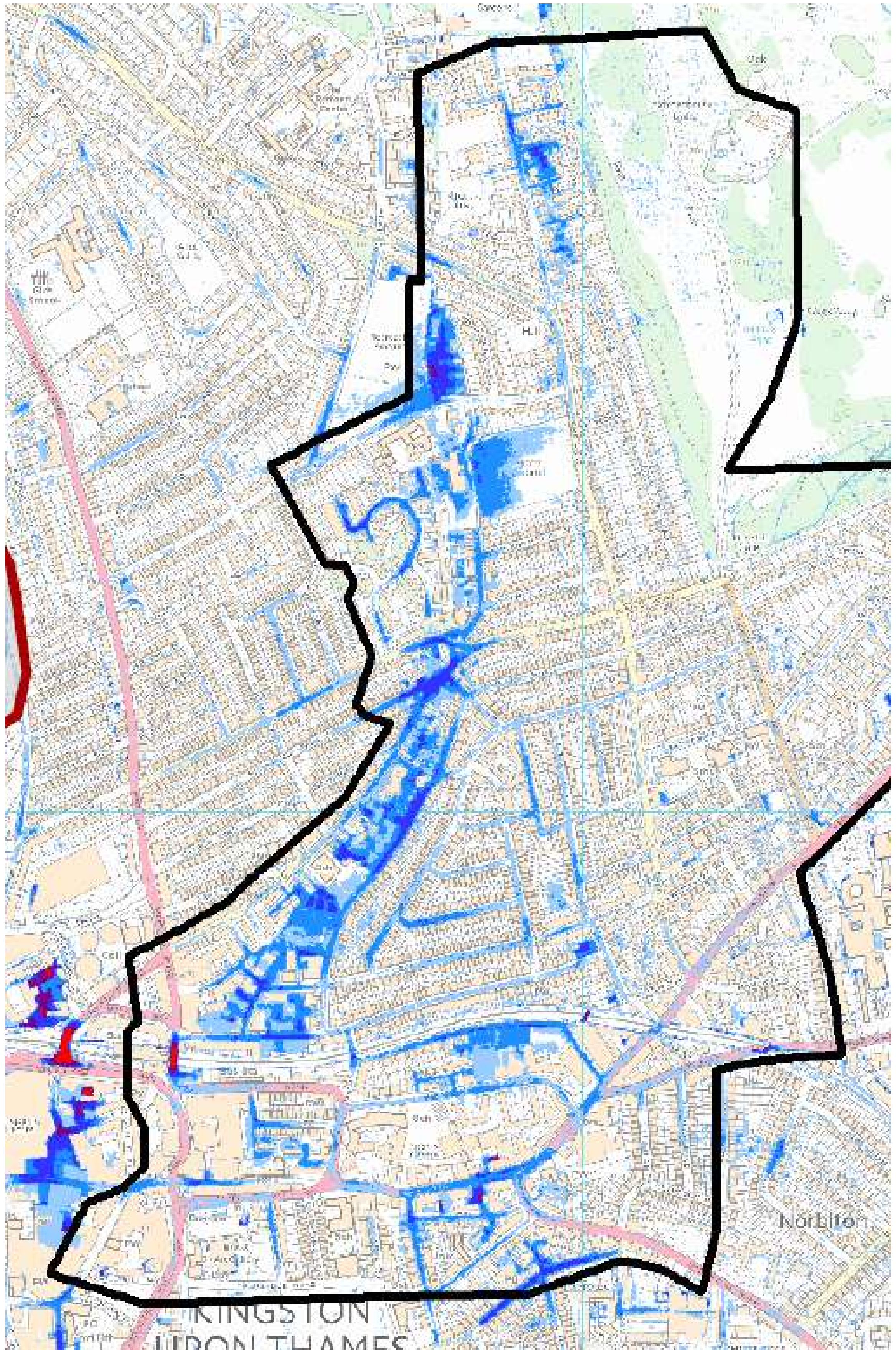
Existing TUFLOW Model	New InfoWorks ICM Model	Key
		Flood Depth (m) < 0.1 >= 0.1 >= 0.25 >= 0.5 >= 1 >= 1.5

Surface Water Flooding – 1 in 25 Years

Existing InfoWorks ICM Model	New InfoWorks ICM Model	Key
		Flood Depth (m) < 0.1 >= 0.1 >= 0.25 >= 0.5 >= 1 >= 1.5

Surface Water Flooding – 1 in 50 Years

Existing InfoWorks ICM Model



New InfoWorks ICM Model

Key

Flood Depth (m)

- < 0.1
- >= 0.1
- >= 0.25
- >= 0.5
- >= 1
- >= 1.5

APPENDIX E

Highway Drainage Banded Effective Infiltration Rate Parameters

Model ID	Rate (mm/hr)
Inf-0.02	13.58
Inf-0.05	19.46
Inf-0.1	26.67
Inf-0.15	32.26
Inf-0.2	37.89
Inf-0.25	42.35
Inf-0.3	48.00
Inf-0.35	55.38
Inf-0.4	64.00
Inf-0.45	72.00
Inf-0.5	83.72
Inf-0.55	97.30
Inf-0.6	114.29
Inf-0.65	131.71
Inf-0.7	156.52
Inf-0.75	180.00
Inf-0.8	220.82
Inf-0.85	260.62
Inf-0.9	334.02
Inf-0.95	457.14
Inf-0.98	720.00

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